

# The 1996–1997 Fading of V651 Mon, the Binary Central Star of the Planetary Nebula NGC 2346

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## Abstract

V651 Mon is the binary central star of the bipolar planetary nebula NGC 2346. The star showed the second-ever deep fading in 1996–1997, which was presumably caused by obscuration by a dust cloud in the planetary nebula, as was proposed to explain the 1981–1985 event. The entire duration of the 1996–1997 event was  $\sim 400$  d, remarkably shorter than the 1981–1985 event, suggesting that the obscuring body was smaller or had a larger tangential velocity. The most remarkable feature in this event was the presence of a sharply defined transient clearing (brightening). From the time-scale of the variation, we propose an upper limit of the projected scale of several times  $\sim 10^{11}$  cm of the structure responsible for the brightening. This observation provides the first evidence for a sharply defined, small lucent structure within the obscuring body around the central star of NGC 2346

Key words: ISM: planetary nebulae: individual (NGC 2346) — stars: binaries: close — stars: variables: other — stars: individual (V651 Mon)

## 1 Introduction

V651 Mon is the binary central star of the bipolar planetary nebula NGC 2346. The 15.991-d binary consists of an A5 V star, which emits most of the visual light, and a hot ( $T_{\text{eff}} \sim 10^5$  K) subdwarf, which emits the most of the ultraviolet light (Méndez, Niemela, 1981). This binary has received special attention since its fading episode starting in 1981 (Kohoutek, 1982).

The fading initially showed a strong modulation

with the orbital period. Subsequent observations led to a picture of a passing cloud (within the planetary nebula) in front of the binary: eclipse-like fadings in the visual light occur when the orbiting A5 V star passes behind the cloud (for a review on this object, see Costero et al. (1986)). Costero et al. (1986) expect, from the amount of dust from IRAS observations, that the probability of such passages is very small. In fact, plate searches could not detect any similar events between 1899 and 1981 (Schaefer, 1983). Further detailed photoelectric observations only caught small variations (Kohoutek et al., 1992), or a transient short fading (Grothues, Kohoutek, 1993).

In spite of a prediction by Costero et al. (1986), the second-ever deep fading was reported in 1996 September (Overbeek, 1996). We started CCD observations upon this alert.

## 2 Observation

The observations were made on 38 nights between 1996 November 14 and 1998 January 2, using a CCD camera (Thomson TH 7882,  $576 \times 384$  pixels, on-chip  $2 \times 2$  binning adopted) attached to the Cassegrain focus of the 60 cm reflector (focal length=4.8 m) at Ouda Station, Kyoto University (Ohtani et al., 1992). An interference filter was used, which had been designed to reproduce the Johnson *V* band. The exposure time was 20–60 s, depending on the brightness of the object. The frames were first corrected for standard debiasing and flat fielding, and were then processed by a microcomputer-based photometry package developed by one of the authors (TK). We employed a PSF profile fitting procedure for the central star in order to minimize any contamination from the planetary nebula. The magnitudes were determined relative to GSC 4815.3644 ( $V=11.76$ , VSNET chart), whose constancy during the run was confirmed using GSC 4815.3177. Table 1 lists the log of observations.

## 3 Discussion

Figure 1 presents the overall course of the 1996–1997 fading episode. Visual observations were reported to VSNET<sup>1</sup> (VSNET is an international network of variable star observers, designed to make collaborative studies on selected variable stars). All observers used comparison stars calibrated in the *V*-band. The present CCD *V*-band observations are also shown (open circles). The total duration of the event was  $\sim 400$  d, which is remarkably shorter than the 1981–1985 event.

Figure 2 shows an overall light curve from our CCD observations. The CCD observation started when the

<sup>1</sup>{ <http://www.kusastro.kyoto-u.ac.jp/vsnet/> }.

Table 1: Log of observations

Mid-JD*	Mean mag <sup>†</sup>	Error <sup>‡</sup>	N <sup>  </sup>
50402.322	1.195	0.038	5
50404.199	0.685	0.054	3
50407.247	1.120	0.043	5
50427.089	1.860	0.025	5
50429.107	1.537	0.021	5
50432.160	1.854	0.021	5
50438.142	1.626	0.056	3
50439.044	1.478	0.088	3
50441.050	2.142	0.030	3
50442.050	1.935	0.039	3
50443.076	1.540	0.051	3
50445.094	1.164	0.016	5
50448.078	1.582	0.029	5
50449.016	2.095	0.065	3
50450.128	2.010	0.160	2
50451.033	1.911	0.083	6
50452.238	1.805	0.021	3
50452.969	1.410	0.014	3
50455.110	1.925	0.015	5
50461.094	1.611	0.062	3
50462.073	1.538	0.024	3
50464.107	2.098	0.036	3
50468.998	2.133	0.055	3
50507.048	2.496	0.015	3
50507.960	2.279	0.025	5
50509.037	2.296	0.021	5
50512.966	2.495	0.017	5
50515.988	2.401	0.037	5
50518.948	2.090	0.036	5
50535.917	2.249	0.095	7
50537.921	1.500	0.012	5
50538.930	1.162	0.028	3
50539.921	0.479	0.089	3
50551.924	2.236	0.019	5
50552.938	2.204	0.058	5
50711.326	-0.180	0.022	5
50814.133	-0.442	0.053	3
50816.157	-0.581	0.027	3

\* JD-2400000.

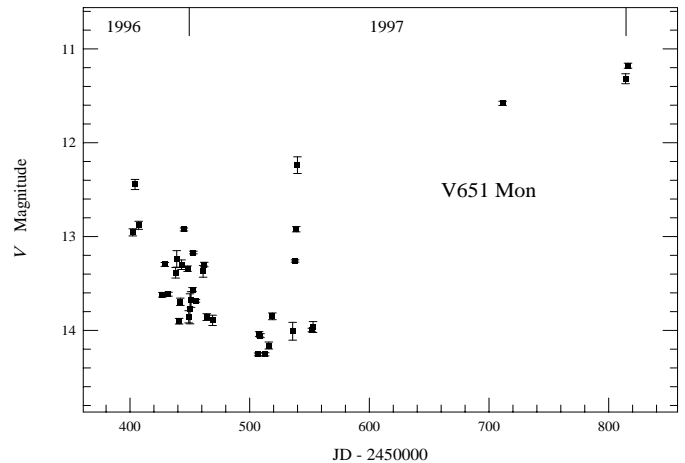
<sup>†</sup> Magnitude relative to GSC 4815.3644.<sup>‡</sup> Standard error of nightly average.<sup>||</sup> Number of frames.

Figure 2: Light curve of V651 Mon from the present CCD observations.

1996–1997 fading episode reached close to its minimum. The object recovered to its normal magnitude during the latest two observations (at the end of 1997).

Following the interpretation by Costero et al. (1986), the cloud responsible for the fade was either smaller or had a larger tangential velocity. The total depth of the fading ( $\sim 2.7$  mag) may be slightly smaller than the extreme value reported in the 1981–1985 event. This difference, however, may be a result of a systematic difference of the measurements: in the 1981–1985 event, the aperture background subtraction technique in photoelectric photometry was employed in order to measure the faint object against the bright nebular background, while the present observations of the 1996–1997 event used PSF fitting of the stellar profile on two-dimensional CCD images. By taking this effect into account, the depth was found to be roughly comparable to that of the 1981–1985 event, implying that the opacity of the cloud is similar.

Another notable feature of the present event is the presence of a sharply defined transient brightening around JD 2450540. The enlarged light curve around this brightening is shown in figure 3. Although visual observations reported to VSNET suggest the presence of a weak 16-d periodicity, as was observed in the 1981–1985 event, no other brightening with a similar amplitude was observed around the binary phase of the brightening. Since the binary motion of the central close binary is expected to be much faster than the tangential velocity of the orbiting cloud [Costero et al. (1986) proposed  $0.14 \text{ km s}^{-1}$  for the 1981–1985 event], the sharply defined brightening is considered to more reflect the orbital motion of the A5 V star against the foreground cloud. By assuming  $K_1 = 16.4 \text{ km s}^{-1}$  (Méndez, Niemela, 1981), the sharp structure of the light curve

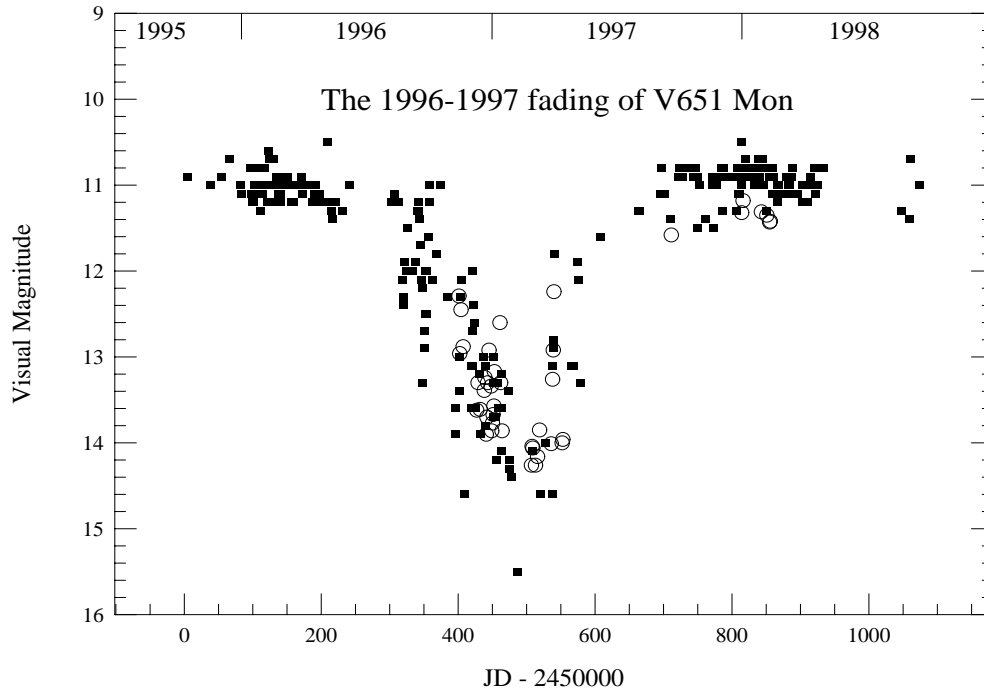


Figure 1: Visual light curve of the 1996–1997 fading from observations reported to VSNET (filled squares). CCD V-band observations (open circles) from table 1 are also shown. The total duration of the deep fading episode was  $\sim 400$  d.

corresponds to an upper limit of the projected scale of several times  $\sim 10^{11}$  cm. This scale is by a factor of about ten smaller than the entire cloud responsible for the 1981–1985 fade, which was estimated to have a size of  $2\text{--}5 \times 10^{12}$  cm (Costero et al., 1986).

This observation not only provides the first evidence for such a sharply defined, small lucent structure within the obscuring body around the central star of NGC 2346, but also the first-ever direct determination of the dimension of a fine structure within a dust cloud of a planetary nebula.

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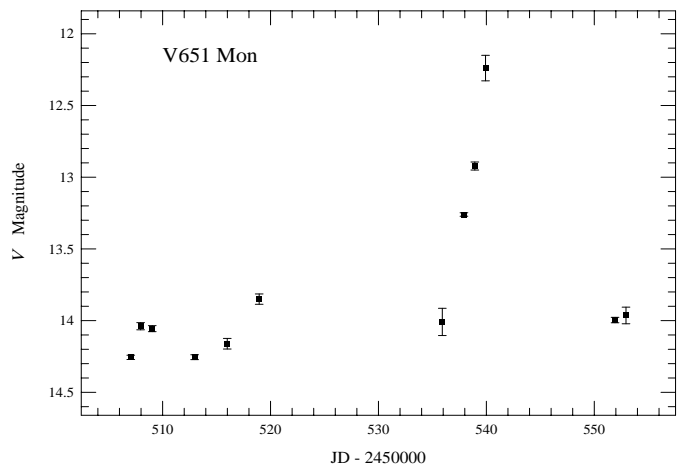


Figure 3: Transient, sharp brightening observed during the fading episode.

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